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New Method to Improve Electrical Characteristics of low-k Dielectrics in Cu-Damascene Interconnections

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ABSTRACT

The rinsing of copper damascene interconnection structures with CO_2 supercritical fluid (SCF) has been found to be effective in removing moisture from the low-k dielectric used in the interconnections. This treatment improved the breakdown voltage and TDDB lifetime of comb-shaped test structures, although it had a somewhat negative effect on the IV curves of blanket films.

INTRODUCTION

Interconnection technology is now shifting from the 90-nm node to the 65-nm node, and reliable interlayer insulating films with a dielectric constant in the range of 2.4 ~ 2.8 are urgently required. [1] One of our goals is to realize fine copper damascene interconnections buried in a low-k dielectric through the use of an etching technology that does not employ perfluorocarbons (PFCs). One candidate for a low-k dielectric that can be etched with non-PFC gases is an aromatic compound that we are working with. ASET is now developing an etching technology that employs only nitrogen and hydrogen to pattern that organic film.

The film requires good mechanical, electrical and thermal properties in order to satisfy the requirements of LSI processing and field reliability. This study focused on moisture removal because moisture affects the electrical properties of the organic film. The rinsing of materials with a supercritical fluid (SCF) is now becoming a common way to remove particles and contaminants in LSI processing. CO_2 in the supercritical phase is thought to capture water molecules easily. ASET is studying a CO_2 SCF rinse as a way of removing moisture from organic film. [2] The behavior of CO_2 will be introduced and the reason for difference between comb-shaped structure and blanket film after CO_2 SCF treatment will be considered.

EXPERIMENTAL RESULTS AND DISCUSSIONS

Test structure fabrication

Capacitors with comb-shaped electrodes were fabricated in a one layer copper damascene interconnection structure and the current between adjacent electrodes were measured. As illustrated in figure 1, the interlayer structure consisted of an organic film (200 nm thick) and an appropriate hard mask film (100 nm thick) deposited on the base layers. After the deposition of a barrier metal and copper, all the metals were chemically and mechanically polished (CMP) and etched. Finally a top layer of SiC film (30 nm thick) was deposited over the whole wafer. In this test structure, both the line widths and the spacing ranged from 0.08 μm to 1.0 μm. Generally an ohmic current flows between comb-shaped electrodes at electric field strengths of up to ~1 MV/cm, and a Frenkel-Poole-type current flows when the electric field strength is over 1 MV/cm.

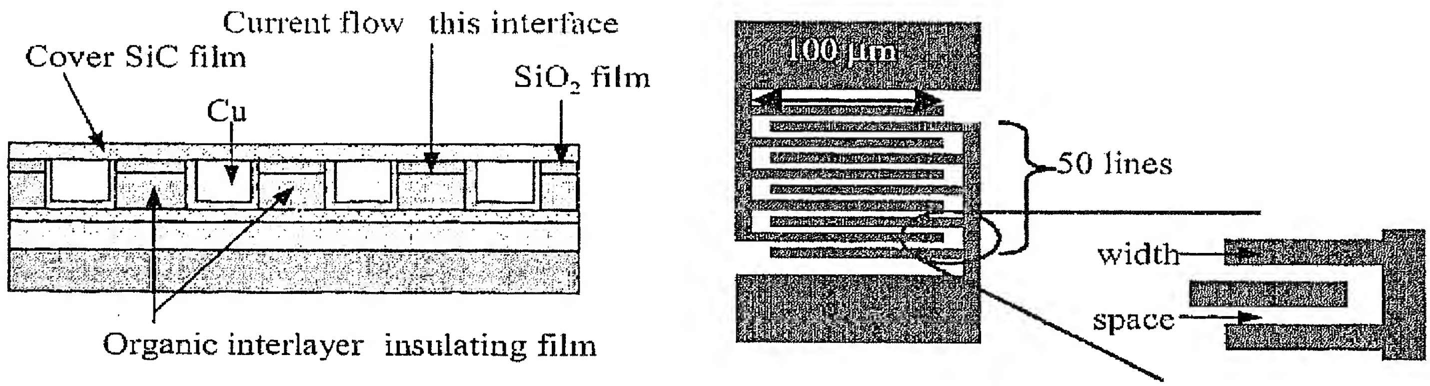

Figure 1. Schematic diagram of comb-shaped test structure

However, when samples are left for a few months in an ordinary room environment, as shown in figure 2, the current sometimes increases abruptly at a very low voltage, which obstructs the analysis of the electrical properties. In this study, this phenomenon is defined to be the breakdown of the organic film.

Supercritical fluid treatment

Based on empirical knowledge, the reason for this type of breakdown seems to be the absorption of moisture. Up to now, there has been no satisfactory method of removing moisture from the dielectric film in Cu interconnections. The use of SCF is one way to rinse fine structures because of its high wetting ability. Since there is no liquid-vapor interface, SCF can

moisten even very fine structures, penetrating even the tiny crevices and gaps in Cu interconnections, and moreover, the drying process produces no capillary stress.

To extract and remove moisture and certain materials, ASET uses CO_2 SCF. Wafers are first rinsed with de-ionized water for 3 min. Next, CO_2 gas is fed into the chamber, and the pressure is raised until the CO_2 becomes supercritical. The CO_2 CSF then flows over the interconnection structure. Finally, the pressure is reduced and the wafers are taken out of the chamber.

Electrical properties

IV measurements revealed that treatment with CO_2 SCF increased the breakdown voltage of comb-shaped capacitors like as figure 3. An analysis of the current density for electric field strengths in the range of 1 ~ 3 MV/cm showed the current to be the Frenkel-Poole-type and to be determined solely by the electric field strength.

To investigate the mechanism of that improvement, the current density at 1 MV/cm is carefully measured before and after the SCF treatment. The figure 4 illustrates that 1 MV/cm is the boundary where the ohmic current turns into the Frenkel-Poole-type. The initial current density distribution at 1 MV/cm centered around a value of 1×10^{-7} A/cm^2; and after SCF treatment, the value was lower. The decrease in current density means that moisture or some other material that degrades the breakdown voltage was removed. Moreover, the TDDB lifetime of SCF-treated samples was longer than that of untreated samples; and there is a negative correlation between the current at 1 MV/cm and the TDDB lifetime.

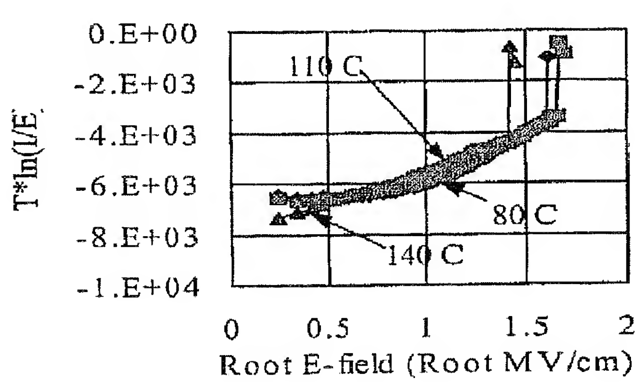

Figure 2. Degradation of samples that are left for 3 months. S/W = 0.18/0.54 μm

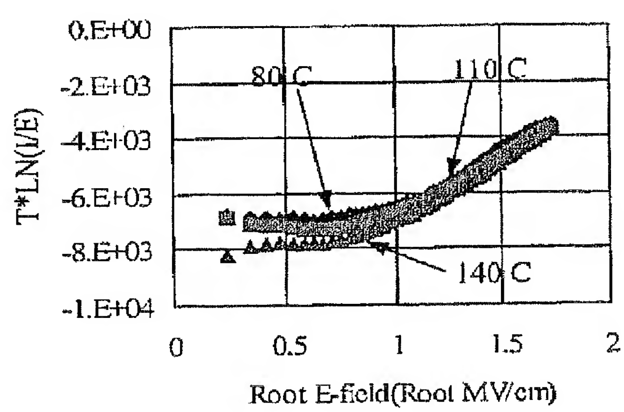

Figure 3. Improved I-V curves after SCF

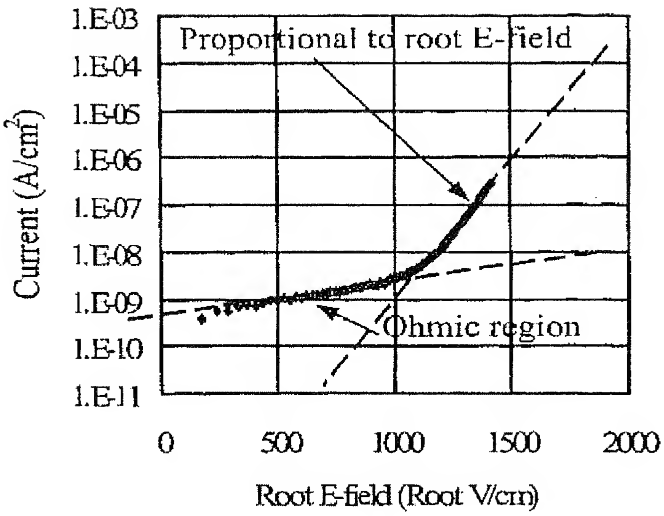

Figure 4. Current density at 1 MV/cm

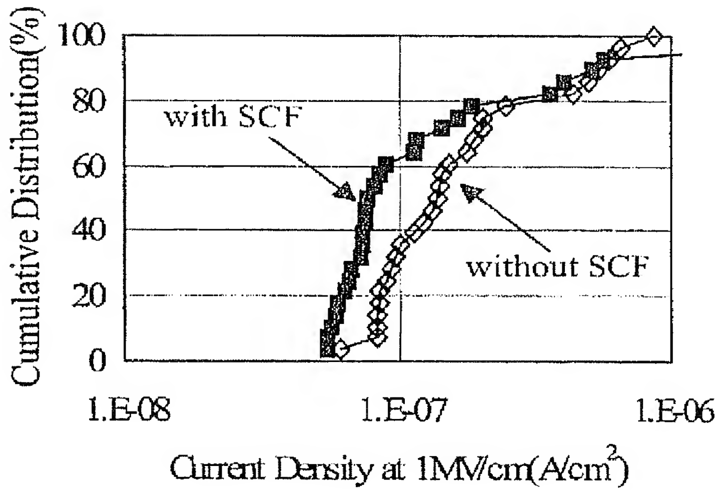

Figure 5. Current distribution of samples with and w/o SCF treatment

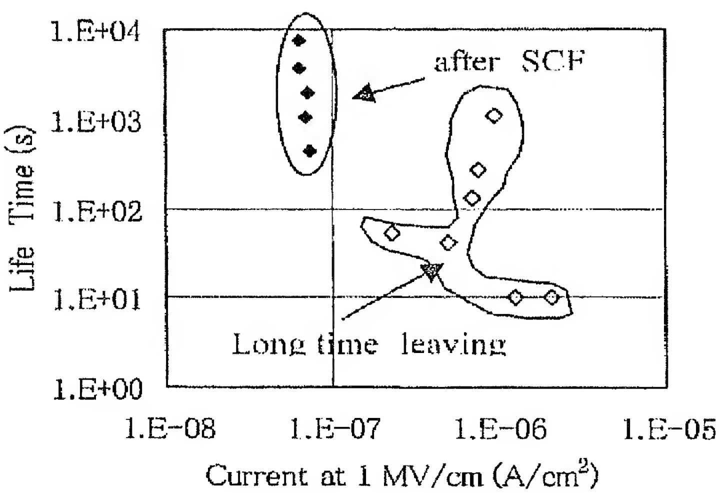

Figure 6. SCF effect on TDDB lifetime of samples left for a long time

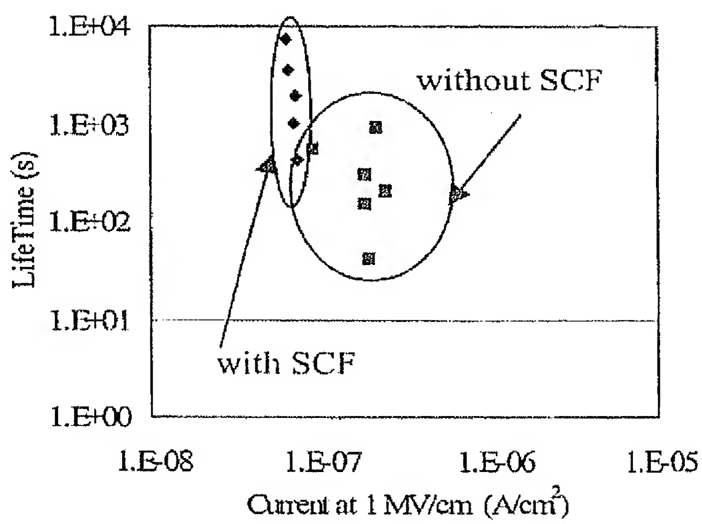

Figure 7. SCF effect on samples after fabrication

An interesting point is that, since, after CMP, the current between comb-shaped electrodes is thought to flow mainly on the polished surface, these results indicate that SCF treatment affects the CMP interface through the top layer. One explanation might be that the SCF penetrates

through the SiC cover layer. However, there may be many fine crevices and gaps at the surface of interlayer structure that are not completely covered with the SiC film; and it is quite probable that water penetrate them during CMP.

Blanket film

In addition to comb-shaped test structures, bulk films on a bare low-resistivity wafer were also investigated. A blanket organic film was rinsed with CO_2 SCF before the evaporation of an Al electrode. Then, the current that flowed perpendicular to the film surface was measured, and the value was compare with that for untreated film. Surprisingly, the current density at 1 MV/cm, which is shown in figure 8, was found to be slightly larger for a treated sample. This indicates that the effect of SCF on the conductivity mechanism is different for a comb-shaped test structure and blanket film capacitor from. This difference may be attributable to molecules of the de-ionized water used in the first step of the SCF treatment that either adsorb to the surface of the organic or sink into any gaps. Some degradation in the IV curves would be observed if there were any residual water molecules after the SCF treatment.

Discussions

Because an inclination after Frenkel-Poole analysis does not change by the SCF treatment, it is obvious that this treatment does not affect conduction mechanism. The SCF treatment just results in a reduction of current density in an ohmic field, which leads to the increase of TDDB lifetime.

Through a CMP process, test samples are washed by wet solutions and water molecules easily enter into crevices and gaps locating at exposed surface of dielectrics and accumulate there. When samples are left for a long time in a bad circumstance after fabrication, the moisture enter into dielectric layers through the cover films. The SCF treatment can remove that water molecules and moisture which locate between electrodes, that results in the improvement of degradations.

On the other hand, the SCF treatment can not improve more of the blanket film which possesses a pretty good electrical characteristics. The SCF treatment before an electrode evaporation may bring water molecules as an undesirable contamination that degrade I-V curves and are hard to remove after an electrode evaporation because they locate under the electrode.

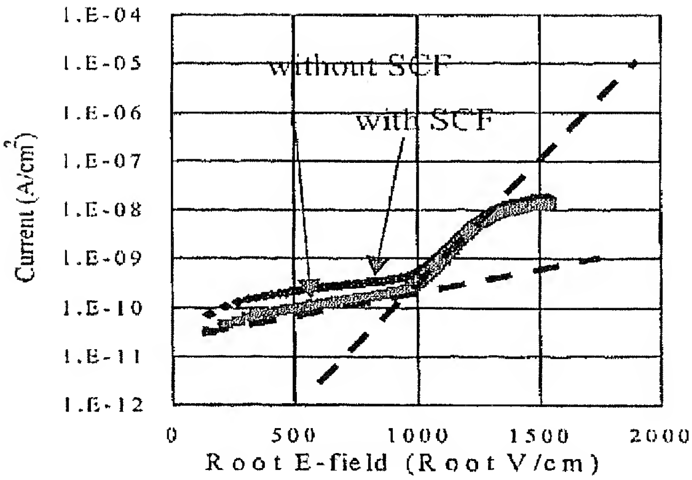

Figure 8. SCF effect on organic dielectric film (blanket) before electrode evaporation

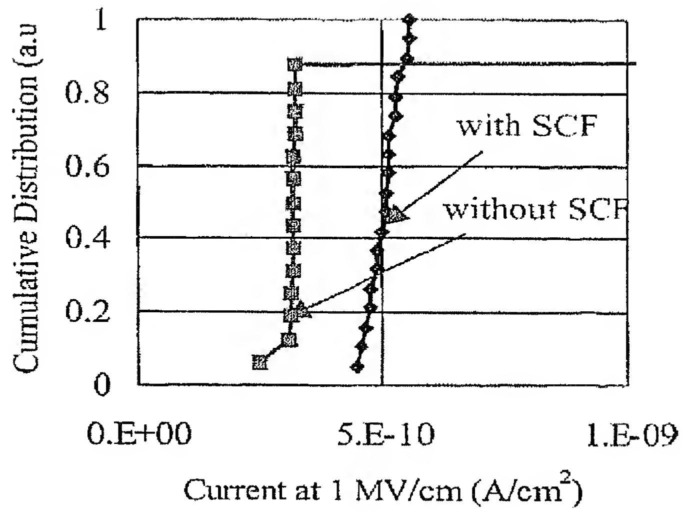

Figure 9. Current distribution of organic dielectrics

CONCLUSION

The degradation in the breakdown voltage and the current density at 1 MV/cm of comb-shaped test structures is probably due to the absorption of moisture. It was found that the electrical characteristics could be improved by rinsing in CO_2 SCF, even after the copper interconnection process. The correlation between the current density at 1 MV/cm and the TDDB lifetime is better for SCF-treated samples than for samples left in an ordinary room environment for 3 months. Thus, the IV characteristics can be improved by rinsing in CO_2 supercritical fluid, even after the copper damascene process, provided that the reason for the degradation is the absorption of moisture.

ACKNOWLEDGMENTS

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